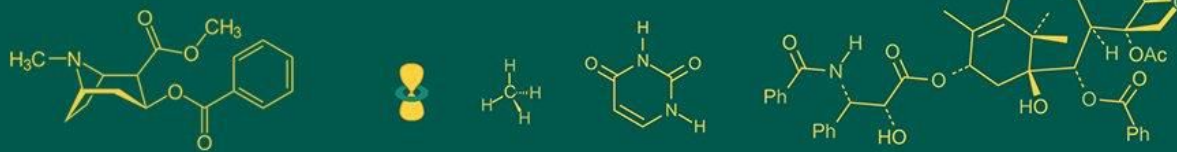


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Impact of active packing on the shelf-life of chicken drumsticks under refrigeration storage

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Abstract

The present study evaluated the effectiveness of aerobic packaging (C) and active packaging (AP) incorporating an oxygen scavenger on the quality attributes and shelf life of chicken meat drumsticks stored under refrigerated conditions (4 ± 1 °C). Chicken drumsticks were packaged under aerobic and active packaging systems and assessed at regular intervals over a 9-day storage period for physicochemical, oxidative, microbiological, and sensory parameters. The results demonstrated that active packaging significantly ($p < 0.05$) reduced headspace oxygen concentration, thiobarbituric acid (TBA) values, tyrosine values, and microbial counts compared to aerobic packaging throughout refrigerated storage. Furthermore, sensory attributes and instrumental color characteristics were better preserved in actively packaged samples. Based on microbiological and sensory acceptability limits, aerobic-packaged chicken meat remained acceptable for up to 5 days, whereas active packaging effectively extended the shelf life to 9 days under refrigerated storage conditions. The findings indicate that incorporating an oxygen scavenger into active packaging is a promising strategy for enhancing the quality, stability, and extending the refrigerated shelf life of chicken meat.

Keywords: Chicken drumsticks, aerobic packaging, active packaging, Oxygen scavenger, shelf-life, refrigeration storage

Introduction

Fresh poultry meat is inherently perishable: high water activity, abundant nutrients, and a near-neutral pH create an environment that favors rapid microbial growth and oxidative reactions, which together drive deterioration of color, flavor, texture, and overall acceptability during chilled storage. This rapid quality loss presents a persistent challenge for producers, processors, and retailers seeking to deliver safe, attractive chicken products with satisfactory shelf lives. (Li *et al.*, 2022) [17].

Traditional aerobic retail packaging is simple and inexpensive but leaves package headspace oxygen available to accelerate lipid and protein oxidation and to support aerobic spoilage microorganisms, thereby limiting the refrigerated shelf life of fresh poultry. Because oxygen-mediated reactions also hasten discoloration and sensory deterioration, there is growing impetus within the meat industry to adopt packaging strategies that actively control the package microenvironment rather than merely enclosing the product. (Gupta, 2023) [9].

Active packaging encompasses a set of technologies that actively interact with the food or its surrounding atmosphere to retard spoilage processes, preserve quality, and improve safety. Among active approaches, oxygen-scavenging systems are particularly relevant to fresh meats because they reduce residual and ingress oxygen in the headspace, thereby limiting oxidative rancidity and suppressing aerobic spoilage flora. Recent reviews and applied studies have documented that oxygen scavengers most commonly iron-based sachets or incorporated scavenging layers can markedly decrease headspace oxygen and slow deterioration across a range of meat and seafood products. (Kadirvel *et al.*, 2024) [10].

Comparative investigations have shown that active packaging strategies (including oxygen scavengers, antimicrobial coatings, and tailored film systems) can outperform conventional aerobic packaging and, in some cases, rival or complement modified atmosphere packaging (MAP) or edible coatings in extending chilled shelf life and preserving sensory and instrumental quality attributes of chicken cuts. However, the magnitude of benefit depends on product characteristics, storage temperature, packaging configuration, and the

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specific scavenger or functional component used, underscoring the need for product-specific validation. (Ntzimani *et al.*, 2023) [21].

Despite the demonstrated potential of oxygen-scavenging active packaging, there remain practical and knowledge gaps regarding their performance on whole poultry pieces under typical retail refrigerated conditions especially with respect to integrated assessment of physicochemical (oxidative markers such as TBA and tyrosine), microbiological, instrumental color, and sensory endpoints over commercially relevant storage periods. Moreover, advances in scavenger chemistries and film technologies (including biodegradable and non-iron scavenging systems) demand updated, application-focused evaluations to inform adoption by industry. (di Giuseppe *et al.*, 2022) [6].

This study addresses those gaps by systematically comparing conventional aerobic packaging and an active packaging system containing an oxygen scavenger for chicken drumsticks stored at ($4\pm 1^\circ\text{C}$). We conducted a comprehensive evaluation covering headspace oxygen concentration, oxidative indices (TBA, tyrosine), microbial counts, instrumental color, and sensory assessments over a nine-day refrigerated storage period. The objective was to quantify the extent to which oxygen-scavenging active packaging can preserve quality attributes and extend the refrigerated shelf life of chicken drumsticks under conditions representative of cold-chain retail storage.

Materials and Methods

Meat sample

Broiler chicken drumsticks (100 ± 10 g) were obtained fresh from a retail source in Hyderabad, Telangana, India, and immediately transferred to the Packaging Laboratory of ICAR-National Meat Research Institute under controlled chilled conditions ($4\pm 1^\circ\text{C}$). Before packaging, visible adipose tissue and connective matter were removed, and all preparation steps were performed aseptically using sanitized equipment.

Packaging of the chicken drumsticks

The experiment comprised two packaging treatments: a control group (C), in which chicken drumsticks were packaged under aerobic conditions without an active component, and an active packaging group (AP) incorporating an oxygen scavenger (DRY BAG, 30 cc O_2 absorber) (Fig. 1). Prior to sample placement, packaging trays were exposed to ultraviolet radiation for 30 min to ensure surface sterilization. Individual chicken drumsticks were then placed into pre-sterilized trays composed of ethyl vinyl alcohol (EVOH), with an overwrap film of polyethylene terephthalate (PET) and polypropylene (PP). For the AP treatment, the oxygen scavenger sachet was securely attached to the inner side of each tray before sealing. All trays were hermetically sealed using a tray-sealing machine (ETS 300 GS, Elixir Technologies, Bangalore, India) (Fig.2, Fig.3). The packaged samples were stored under refrigerated conditions ($4\pm 1^\circ\text{C}$) and evaluated at regular intervals (days 1, 3, 5, 7, and 9) for physicochemical, microbiological, and sensory quality attributes.

Physico-chemical Analysis

pH Measurement

The pH of chicken drumsticks was recorded using a calibrated handheld digital pH meter (Hanna Instruments, HI

98163, Romania). Calibration was performed with standard buffer solutions (pH 4.0 and 7.0). Measurements were taken at two distinct points within each sample, and mean values were used for analysis.

Free Fatty Acids (FFA)

Free fatty acid content was estimated according to Koniecko, (1979). Finely minced meat (5 g) was homogenized with chloroform in the presence of anhydrous sodium sulphate and filtered. The filtrate was titrated with 0.1 N alcoholic potassium hydroxide using phenolphthalein as an indicator. FFA levels were expressed as percent oleic acid [15].

Thiobarbituric Acid value (TBA)

Lipid oxidation was determined using the TBARS method (Witte *et al.*, 1970). Meat samples were extracted with chilled 20% trichloroacetic acid, centrifuged, and reacted with thiobarbituric acid reagent. After heating, absorbance was measured at 532 nm using a UV-visible spectrophotometer. Results were calculated from a malonaldehyde standard curve and expressed as mg MDA/kg sample [27].

Tyrosine Value

Proteolytic changes were assessed by estimating tyrosine content following Strange *et al.*, (1977). Meat samples were homogenized with chilled trichloroacetic acid and filtered. The extract was reacted with sodium hydroxide and Folin-Ciocalteu reagent, incubated, and the absorbance was read at 730 nm. Tyrosine concentration was calculated using a standard curve and expressed as mg/100 g of sample [24].

Instrumental color analysis (L^* , a^* and b^*)

The instrumental color was measured by using a color reader (Konica Minolta, CR-20, Japan). The meat sample color readings of Lightness (L^*), Redness (a^*), and Yellowness (b^*) color units were taken at 5 different places on the meat surface, and an average measurement was determined.

Head Space Gas Concentration

Headspace levels of O_2 , CO_2 , and N_2 were quantified using a gas analyzer (Checkmate 3, Dansensor, Mocon, Denmark). Measurements were conducted prior to sensory and quality analyses. Gas sampling was performed by inserting a needle probe through a gas-impermeable septum attached to the package. The probe, connected to the analyzer via flexible tubing, was positioned at two different locations within each package, and the mean values were recorded.

Microbial Analysis

Microbiological quality of chicken drumsticks during refrigerated storage was evaluated in accordance with standard methods described by APHA (2007) [1]. Commercial dehydrated media (HiMedia Laboratories Pvt. Ltd., Mumbai, India) were used for microbial enumeration. Meat samples (10 g) were aseptically homogenized with 90 mL of sterile 0.1% peptone water to obtain a 10^{-1} dilution, followed by serial dilutions prepared using the same diluent. All analyses were performed in duplicate, and results were expressed as $\log_{10}$ CFU/g. Psychrophilic bacteria were enumerated on plate count agar after incubation at $4\pm 1^\circ\text{C}$ for 14 days, yeast and mold counts were determined on acidified potato dextrose agar incubated at 25°C for 7 days, and coliforms were enumerated on violet red bile agar after incubation at $37\pm 1^\circ\text{C}$ for 48 h. Microbial acceptability of samples was

interpreted based on generally accepted limits for fresh poultry meat, with samples exceeding these limits considered microbiologically unacceptable.

Sensory Evaluation

A semi-trained panel of ten members (faculty and postgraduate students) evaluated the samples for appearance, color, odor, and surface sliminess using a five-point descriptive scale (5 = extremely desirable; 1 = extremely undesirable) based on (Colle, 2020) American Meat Science Association guidelines [3].

Statistical Analysis

Data were analyzed using two-way ANOVA (SPSS v16.0, Chicago, USA). Mean differences among treatments and storage days were compared using Duncan's Multiple Range Test (DMRT), with significance accepted at ($P < 0.05$).

Results and Discussion

pH Changes

The pH of chicken drumsticks increased progressively in both treatments during refrigerated storage (Table 1), reflecting ongoing biochemical and microbial activities. However, the increase was significantly ($P < 0.05$) more pronounced in the Control samples after day 5 compared to T₂. The rapid rise in pH in aerobic packaging can be attributed to enhanced microbial proliferation and proteolytic activity, resulting in the accumulation of alkaline metabolites such as ammonia and biogenic amines (Lázaro *et al.*, 2012). In contrast, AP exhibited a slower rate of pH increase, likely due to partial oxygen removal by the iron-based scavenger, which suppressed the growth of aerobic spoilage microorganisms. Similar trends have been reported by Latou *et al.*, (2014), who observed delayed pH elevation in poultry meat stored with oxygen-scavenging systems under refrigerated conditions [15, 16].

Lipid Oxidation (TBA)

Thiobarbituric acid (TBA) values increased steadily in both treatments throughout storage (Table 1), indicating progressive lipid oxidation. The Control samples showed significantly higher TBA values from day 5 onwards, reflecting accelerated oxidative deterioration under aerobic conditions. In contrast, AP consistently exhibited lower TBA values, demonstrating the effectiveness of oxygen scavenging in limiting oxidative reactions. The reduced availability of oxygen in AP likely restricted free radical formation and subsequent malonaldehyde production. These findings are consistent with those of Demirhan and Candoğan, (2017) [5], who reported lower TBA values in chicken meat packaged with iron-based oxygen absorbers, and (Linares *et al.*, 2007; Nam & Ahn, 2003) noticed lower TBA values in turkey meat and lamb meat stored under low oxygen concentrations, respectively, highlighting the role of oxygen control in preserving lipid stability during chilled storage [18, 20].

Free Fatty Acid Content

Free fatty acid (FFA) levels increased gradually in both groups during storage (Table 1), reflecting lipid hydrolysis mediated by endogenous and microbial lipases. The Control exhibited a significantly higher accumulation of FFAs compared to AP, indicating more pronounced lipolytic degradation under aerobic conditions. The comparatively

lower FFA levels observed in AP suggest that reduced oxygen availability limited microbial growth and enzyme activity associated with lipid breakdown. Similar reductions in FFA accumulation under oxygen-restricted packaging conditions have been reported by Verma *et al.*, (2016), supporting the role of oxygen scavenging in delaying lipolysis in refrigerated meat products [26].

Protein Degradation (Tyrosine Value)

Tyrosine values increased progressively in both groups during refrigerated storage (Table 1), indicating ongoing proteolysis. However, the Control samples recorded significantly ($P < 0.05$) higher tyrosine values than AP at later storage intervals, suggesting accelerated protein degradation under aerobic conditions. The lower tyrosine accumulation in AP can be attributed to reduced oxygen levels, which likely suppressed the activity of spoilage-associated microorganisms known to produce proteolytic enzymes. Comparable observations were made by (Kandeean & Biswas, 2007; Sudheer *et al.*, 2011), who reported reduced proteolytic changes in meat products stored under oxygen-limited packaging environments [12, 25].

Headspace Gas Composition

Headspace gas analysis revealed a gradual decline in oxygen (O₂) concentration and a corresponding increase in carbon dioxide (CO₂) in AP packages during storage (Table 2). In contrast, the Control maintained significantly higher oxygen levels throughout the storage period. The reduction in O₂ levels in AP can be attributed to the oxygen-scavenging action of the iron-based absorber, along with oxygen consumption by resident microflora. The accumulation of CO₂ may be associated with microbial respiration and chemical interactions involving iron oxidation. Similar headspace gas dynamics in oxygen-scavenger-assisted packaging systems have been reported by (Dogra *et al.*, 2022; Rothy *et al.*, 2025), confirming the ability of scavengers to maintain a low-oxygen environment during refrigerated meat storage [7, 23].

Color Stability

Instrumental color parameters (L^* , a^* , b^*) changed significantly during storage in both Control and AP groups (Table 3). The Control samples showed a rapid decline in a^* (redness) values, particularly after day 5 (Fig. 2), indicative of oxymyoglobin oxidation to metmyoglobin under aerobic conditions. This resulted in visible discoloration and reduced visual appeal. In contrast, AP retained significantly higher a^* values during storage, reflecting improved color stability due to reduced oxygen exposure. These findings align with reports by (Chounou *et al.*, 2013; Lu *et al.*, 2020) [2, 19], who demonstrated that oxygen scavenging effectively delays pigment oxidation and color deterioration in refrigerated meat products.

Microbial Quality

Microbial counts increased steadily in both treatments as storage progressed (Table 4). However, the Control exhibited significantly higher psychrophilic, coliform, yeast, and mold counts, exceeding acceptable limits by day 7. In contrast, AP effectively delayed microbial proliferation, maintaining counts within acceptable limits for a longer duration. The suppression of microbial growth in AP is primarily attributed to reduced oxygen availability, which restricted the growth of

aerobic spoilage microorganisms. Similar reductions in microbial load in oxygen-scavenger-assisted packaging have been reported by (Demirhan & Candoğan, 2017; Dogra *et al.*, 2022; Gurunathan *et al.*, 2022) ^[5], highlighting the microbiological advantages of oxygen-controlled packaging systems ^[7, 10].

Sensory Evaluation

Sensory attributes, including appearance, color, odor, and surface sliminess, declined significantly ($P<0.05$) with

increasing storage duration in both treatments (Table 5). The Control samples were rated unacceptable by day 7 due to off-odors, discoloration, and surface slime development (Fig.2). On the other hand, AP maintained acceptable sensory quality up to day 9 (Fig.3), which corresponded well with its lower oxidative and microbial indices of the present study. These observations support the findings of and (Katiyo *et al.*, 2020; Nychas *et al.*, 2008), who emphasized the strong relationship between microbial growth, oxidative deterioration, and sensory rejection in fresh meat products ^[13, 22].



Fig 1: Dry Bag Oxygen Scavenger,



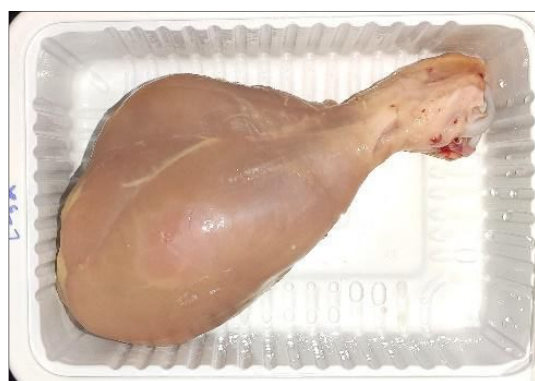
Day-1



Day-3



Day-5



Day-7



Day-9

Fig 2: Control group (C) during refrigeration storage ($4\pm1^{\circ}\text{C}$).

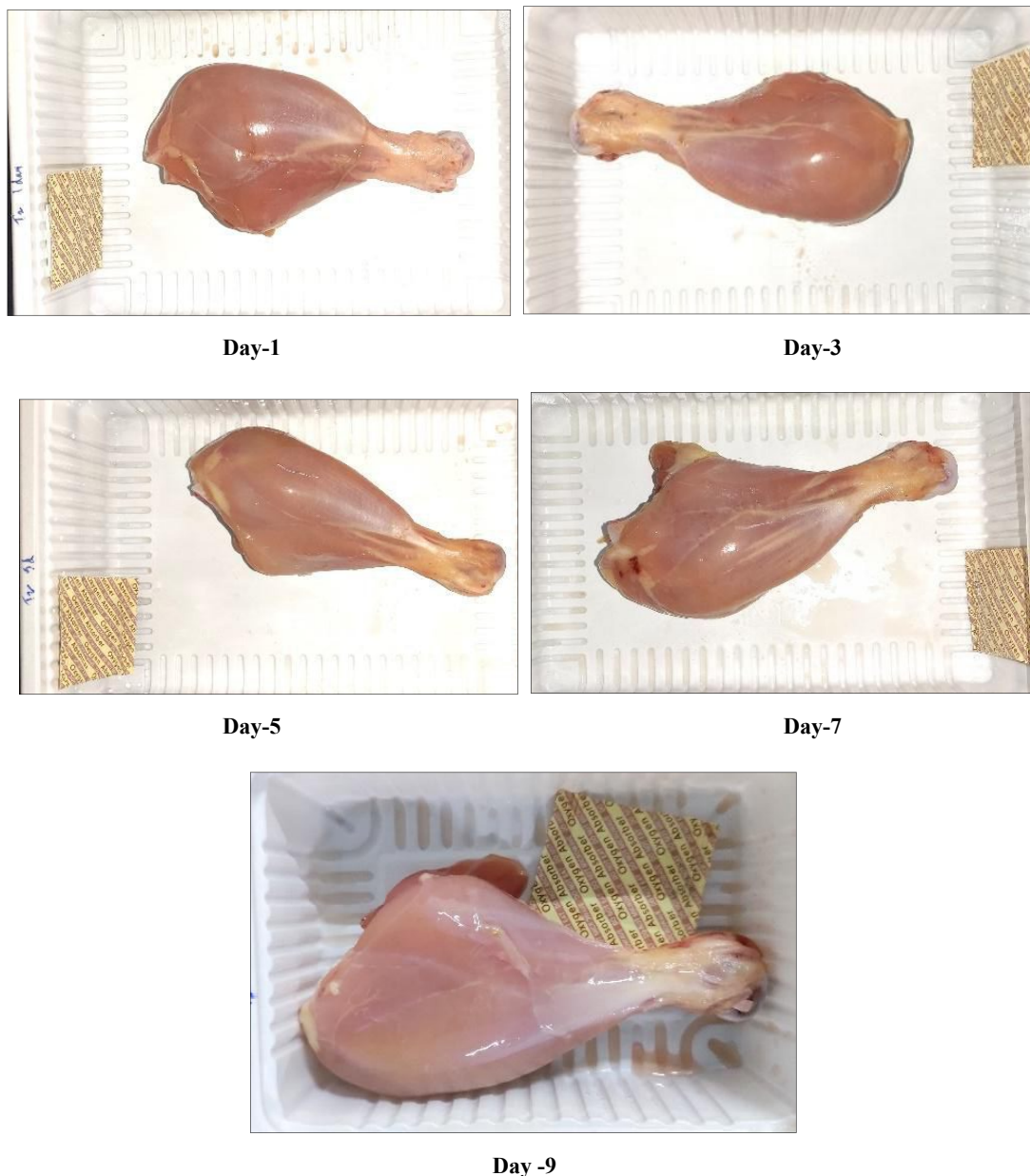


Fig 3: Active packaged samples (AP) under refrigeration storage ($4\pm 1^{\circ}\text{C}$)

Table 1: Effect of Active Packaging on Physico-Chemical parameters of Chicken Meat Drumsticks Under Refrigeration Storage ($4\pm 1^{\circ}\text{C}$).

Parameter	Group	Day 1	Day 3	Day 5	Day 7	Day 9
pH	C	$5.90\pm 0.07^{\text{dB}}$	$6.04\pm 0.04^{\text{d}}$	$6.38\pm 0.15^{\text{cA}}$	$6.39\pm 0.01^{\text{cA}}$	$6.42\pm 0.02^{\text{cA}}$
	AP	$6.14\pm 0.03^{\text{deA}}$	$6.07\pm 0.06^{\text{e}}$	$6.27\pm 0.07^{\text{cB}}$	$6.30\pm 0.01^{\text{cB}}$	$6.34\pm 0.01^{\text{cdB}}$
TBA (mg MDA/kg)	C	$0.12\pm 0.10^{\text{d}}$	$0.14\pm 0.10^{\text{dA}}$	$0.20\pm 0.02^{\text{cA}}$	$0.22\pm 0.10^{\text{cA}}$	$0.24\pm 0.12^{\text{bcA}}$
	AP	$0.11\pm 0.10^{\text{c}}$	$0.11\pm 0.15^{\text{cA}}$	$0.13\pm 0.10^{\text{cB}}$	$0.15\pm 0.05^{\text{bcBA}}$	$0.16\pm 0.01^{\text{bcB}}$
Tyrosine (mg/100 g)	C	$7.12\pm 0.51^{\text{e}}$	$8.12\pm 0.49^{\text{e}}$	$9.50\pm 0.16^{\text{dA}}$	$10.43\pm 0.56^{\text{cdA}}$	$10.75\pm 0.16^{\text{cA}}$
	AP	$7.00\pm 0.48^{\text{f}}$	$7.43\pm 0.17^{\text{ef}}$	$7.87\pm 0.15^{\text{cB}}$	$8.75\pm 0.29^{\text{dB}}$	$10.56\pm 0.34^{\text{cA}}$
FFA (% oleic acid)	C	$0.57\pm 0.006^{\text{eA}}$	$1.07\pm 0.06^{\text{dA}}$	$1.15\pm 0.11^{\text{dA}}$	$1.63\pm 0.09^{\text{cA}}$	$2.17\pm 0.75^{\text{bA}}$
	AP	$0.53\pm 0.13^{\text{fA}}$	$0.63\pm 0.22^{\text{fB}}$	$0.92\pm 0.18^{\text{eAB}}$	$1.10\pm 0.07^{\text{dB}}$	$1.50\pm 0.05^{\text{cB}}$

(N=6) Means with different superscripts in the same column (capital letters) and same row (small letters) differ significantly ($P<0.05$). C- Control without oxygen scavenger; AP - Treatment with O_2 scavenger

Table 2: Effect of Active Packaging on Headspace Gas Concentration of Active Packaged Chicken Meat Drumsticks Under Refrigeration Storage ($4\pm 1^{\circ}\text{C}$)

Parameter	Group	Day 1	Day 3	Day 5	Day 7	Day 9
O_2 (%)	C	$20.21\pm 0.24^{\text{aA}}$	$18.30\pm 0.76^{\text{aA}}$	$15.38\pm 0.59^{\text{bA}}$	$14.91\pm 0.40^{\text{bA}}$	$14.25\pm 1.47^{\text{bA}}$
	AP	$17.96\pm 0.35^{\text{aB}}$	$11.01\pm 1.98^{\text{bB}}$	$5.85\pm 3.05^{\text{cB}}$	$4.02\pm 2.02^{\text{cdB}}$	$1.98\pm 0.92^{\text{cdB}}$
CO_2 (%)	C	$1.97\pm 0.36^{\text{dAB}}$	$3.76\pm 0.85^{\text{d}}$	$6.41\pm 0.83^{\text{c}}$	$8.08\pm 0.08^{\text{bcA}}$	$6.78\pm 0.87^{\text{bcAB}}$
	AP	$1.10\pm 0.14^{\text{cB}}$	$3.37\pm 0.86^{\text{abc}}$	$5.73\pm 1.30^{\text{a}}$	$4.37\pm 1.22^{\text{abB}}$	$4.61\pm 0.64^{\text{abB}}$

(N=6) Means with different superscripts in the same column (capital letters) and same row (small letters) differ significantly ($P<0.05$). C- Control without oxygen scavenger; AP - Treatment with O_2 scavenger

Table 3: Effect of Active Packaging on instrumental color (L^* , a^* , b^*) of chicken meat drumsticks under refrigeration storage ($4\pm1^\circ\text{C}$)

	Grp	Day 1	Day 3	Day 5	Day 7	Day 9
L^*	C	44.25 $\pm$ 1.00 ^{cB}	48.43 $\pm$ 2.21 ^b	48.60 $\pm$ 1.62 ^b	49.11 $\pm$ 0.73 ^{ab}	50.91 $\pm$ 0.35 ^{ab}
	AP	47.63 $\pm$ 0.55 ^{cA}	47.83 $\pm$ 1.02 ^c	48.31 $\pm$ 1.28 ^c	50.37 $\pm$ 0.75 ^{bc}	51.89 $\pm$ 2.06 ^{ab}
a^*	C	4.83 $\pm$ 0.10 ^{aB}	4.34 $\pm$ 0.27 ^a	3.31 $\pm$ 0.17 ^{bB}	2.80 $\pm$ 0.24 ^{bcdB}	1.97 $\pm$ 0.20 ^{dC}
	AP	6.46 $\pm$ 1.07 ^{aA}	4.70 $\pm$ 0.19 ^b	2.97 $\pm$ 0.17 ^{dB}	3.10 $\pm$ 0.31 ^{dB}	3.87 $\pm$ 0.19 ^{bcdB}
b^*	C	12.55 $\pm$ 0.64 ^a	11.24 $\pm$ 0.93 ^a	10.32 $\pm$ 0.48 ^{ab}	8.17 $\pm$ 0.47 ^{bcB}	5.91 $\pm$ 0.80 ^{cB}
	AP	12.97 $\pm$ 0.87 ^a	11.49 $\pm$ 0.87 ^{ab}	10.26 $\pm$ 0.42 ^{bc}	9.45 $\pm$ 0.54 ^{bcdB}	8.96 $\pm$ 0.46 ^{cdA}

(N=6) Means with different superscripts in the same column (capital letters) and same row (small letters) differ significantly ($P<0.05$). C- Control without oxygen scavenger; AP - Treatment with O_2 scavenger

Table 4: Effect of active packaging on microbial counts ($\log_{10}$ cfu/g) of aerobic tray packaged chicken meat (drumsticks) under refrigeration storage ($4\pm1^\circ\text{C}$)

Microbial counts	Group	Day 1	Day 3	Day 5	Day 7	Day 9
Coliform count ($\log_{10}$ cfu/g)	C	1.01 $\pm$ 0.0 ^f	1.15 $\pm$ 0.12 ^{ef}	1.40 $\pm$ 0.17 ^{eA}	1.78 $\pm$ 0.10 ^{dA}	2.60 $\pm$ 0.10 ^{cA}
	T2	1.00 $\pm$ 0.10 ^c	1.13 $\pm$ 0.12 ^c	1.16 $\pm$ 0.11 ^{cAB}	1.18 $\pm$ 0.06 ^{cB}	1.38 $\pm$ 0.22 ^{cB}
Yeast and mold count ($\log_{10}$ cfu/g)	C	1.77 $\pm$ 0.19 ^f	1.88 $\pm$ 0.12 ^f	2.35 $\pm$ 0.02 ^{eA}	2.58 $\pm$ 0.08 ^{deA}	2.85 $\pm$ 0.05 ^{dA}
	T2	1.70 $\pm$ 0.05 ^d	1.79 $\pm$ 0.02 ^d	2.11 $\pm$ 0.06 ^{cB}	2.24 $\pm$ 0.05 ^c	2.69 $\pm$ 0.16 ^{bB}
Psychrophilic count ($\log_{10}$ cfu/g)	C	4.58 $\pm$ 0.06 ^{gA}	5.06 $\pm$ 0.07 ^{fA}	5.44 $\pm$ 0.05 ^e	6.35 $\pm$ 0.02 ^{dA}	6.44 $\pm$ 0.06 ^{dA}
	T2	4.45 $\pm$ 0.03 ^{eA}	4.60 $\pm$ 0.09 ^{deB}	4.93 $\pm$ 0.25 ^c	5.58 $\pm$ 0.11 ^{cAB}	5.98 $\pm$ 0.12 ^{bB}

(N=6) Means with different superscripts in the same column (capital letters) and same row (small letters) differ significantly ($P<0.05$). C- Control without oxygen scavenger; AP - Treatment with O_2 scavenger

Table 5: Effect of active packaging on sensory attributes of chicken meat drumsticks under refrigeration storage ($4\pm1^\circ\text{C}$)

Sensory attributes	Group	Day 1	Day 3	Day 5	Day 7	Day 9
Appearance	C	4.96 $\pm$ 0.02 ^a	4.53 $\pm$ 0.13 ^{aB}	3.03 $\pm$ 0.12 ^{bc}	2.98 $\pm$ 0.09 ^{bB}	2.50 $\pm$ 0.42 ^{cB}
	AP	4.90 $\pm$ 0.06 ^a	4.44 $\pm$ 0.16 ^{aB}	3.81 $\pm$ 0.31 ^{bB}	3.32 $\pm$ 0.41 ^{bB}	3.25 $\pm$ 0.09 ^{bB}
Color	C	4.96 $\pm$ 0.02 ^a	4.61 $\pm$ 0.11 ^{aB}	2.73 $\pm$ 0.19 ^{bc}	2.66 $\pm$ 0.12 ^{bcC}	2.25 $\pm$ 0.31 ^{cC}
	AP	5.00 $\pm$ 0.00 ^a	4.36 $\pm$ 0.11 ^{bB}	3.93 $\pm$ 0.19 ^{cB}	3.41 $\pm$ 0.23 ^{dB}	3.06 $\pm$ 0.11 ^{dB}
Odour	C	5.00 $\pm$ 0.00 ^a	4.81 $\pm$ 0.13 ^a	2.75 $\pm$ 0.13 ^{bc}	2.56 $\pm$ 0.45 ^{bc}	2.31 $\pm$ 0.35 ^{bB}
	AP	5.00 $\pm$ 0.00 ^a	4.81 $\pm$ 0.13 ^a	4.25 $\pm$ 0.26 ^{bB}	3.48 $\pm$ 0.12 ^{cB}	2.75 $\pm$ 0.31 ^{dB}
Sliminess	C	5.00 $\pm$ 0.00 ^a	5.00 $\pm$ 0.00 ^a	3.06 $\pm$ 0.44 ^{bB}	2.87 $\pm$ 0.33 ^{bc}	2.81 $\pm$ 0.20 ^{bB}
	AP	5.00 $\pm$ 0.00 ^a	5.00 $\pm$ 0.00 ^a	4.43 $\pm$ 0.17 ^{abA}	4.06 $\pm$ 0.06 ^{bB}	3.84 $\pm$ 0.32 ^{bA}

(N=6) Means with different superscripts in the same column (capital letters) and same row (small letters) differ significantly ($P<0.05$). C- Control without oxygen scavenger; AP - Treatment with O_2 scavenger

Conclusion

The results of the present study demonstrate that active packaging incorporating an oxygen scavenger is markedly more effective than conventional aerobic packaging in preserving the quality of chicken drumsticks during refrigerated storage. Active packaging significantly restrained oxidative and proteolytic deterioration, microbial proliferation, and color degradation, thereby maintaining sensory acceptability for a longer period. Notably, chicken drumsticks packaged under active packaging remained acceptable for up to 9 days, whereas aerobically packaged control samples retained freshness for only 5 days under refrigerated conditions. Overall, oxygen-scavenger-based active packaging represents a practical and promising approach for enhancing refrigerated shelf life and quality stability of fresh poultry meat, with clear applicability in commercial processing and retail distribution systems.

Author Contribution: G.K. contributed to the study conception, design, fund acquirement, supervision, and editing. Material preparation, data collection, analysis, and the first draft of the manuscript were performed by V.M. The first draft of the manuscript was reviewed by K.S. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest of any competing financial interests or personal relationships that could influence the work reported in this research article.

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Data availability

The research data is available with the corresponding author. The data could be made available upon reasonable request.

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